

AN XMM-NEWTON SURVEY OF ULTRA-LUMINOUS INFRARED GALAXIES

V. Braito^{1,2}, A. Franceschini², R. Della Ceca³, L. Bassani⁴, M. Cappi⁴, P. Malaguti⁴, G.G.C. Palumbo⁵,
M. Persic⁶, G. Risaliti⁷, M. Salvati⁸ and P. Severgnini³

¹Osservatorio Astronomico di Padova, Italy

²Dipartimento di Astronomia, Università di Padova, Italy

³Osservatorio Astronomico di Brera, Milano, Italy

⁴TESRE/CNR, Bologna, Italy

⁵Dipartimento di Astronomia, Università di Bologna, Italy

⁶Osservatorio Astronomico di Trieste, Italy

⁷Dipartimento di Astronomia e Scienza dello Spazio, Università di Firenze, Italy

⁸Osservatorio Astrofisico di Arcetri, Firenze, Italy.

ABSTRACT

We present preliminary results of XMM-Newton observations of 5 Ultra-luminous Infrared Galaxies (ULIRGs), part of a mini-survey program dedicated to 10 ULIRGs selected from the bright IRAS sample. For 3 of them (IRAS 20551-4250, IRAS 19254-7245 and Mkn 231) we find strong evidence for the presence of a hidden AGN, while for two others (IRAS 20110-4156 IRAS 22491-1808) the S/N ratio of the data does not allow us to be conclusive. In particular, we have detected a strong Fe-K line in the X-ray spectra of IRAS19254-7245, with an equivalent width (~ 2 keV) suggestive that most of the energy source in this object is due to a deeply buried AGN.

Key words: Missions: XMM-Newton - X-rays:general - Galaxies:Active

1. INTRODUCTION

The nature of the energy source in Ultra-luminous Infrared Galaxies (ULIRGs), sources with $L_{IR} > 10^{12} L_{\odot}$, is still a debated issue. Although it is widely accepted that both starburst and/or AGN activity may be responsible for the observed luminosity, their relative contribution is still unconstrained. In some cases, even the presence of an AGN is unclear.

Hard X-ray ($E > 2$ keV) studies offer a fundamental tool to investigate the presence of hidden AGNs inside ULIRGs and to obtain quantitative estimates of their contribution to the bolometric luminosity. Indeed some of the ULIRGs, classified as pure starburst based on infrared and optical spectroscopy (i.e. NGC6240, Iwasawa et al. 1999), show spectral properties typical of obscured AGNs, when observed in the hard X-rays.

Previous X-ray studies of ULIRGs with ROSAT, ASCA and BeppoSAX have shown that ULIRGs are often faint X-ray sources (e.g. Risaliti et al. 2000). Combined with their high luminosity in the infrared bands, this could suggest the presence of an obscured AGN. Since ULIRGs are the major contributors to the infrared cosmological background, clarifying the issue of how much of their energy

output comes from obscured AGNs would have important implications on both models for the origin of the IR background, and the IR to X-ray background connection.

To shed light on these problems we are carrying out a mini-survey with XMM-Newton of 10 ULIRGs for which high quality mid-IR and optical spectroscopic data are available. We present here preliminary results on 5 sources, two of which were not detected before in X-rays.

2. THE ULIRGS SAMPLE

The 5 ULIRGs discussed here have been selected from the sample of Genzel et al. (1998) which is complete to 5.4 Jy at $60 \mu\text{m}$ and includes sources with $L \geq 10^{12} L_{\odot}$ in the 12–100 μm band. The FIR selection makes the sample unbiased with respect to absorption, and questions like the relative importance of starburst versus AGN activity can be discussed on a sound physical and statistical ground. In addition, high quality infrared and optical spectroscopic data are also available for all the sources in the sample (Lutz et al. 1999, Veilleux et al. 1999). The infrared luminosity and redshift of these 10 objects, as well as the XMM-Newton exposure time of the 5 objects discussed here, are reported in Table 1. Optical and infrared classifications of the 5 ULIRGs presented here are summarized in Table 2. All ten objects are being observed with XMM-Newton with ~ 20 ksec exposure each. The main goal of these observations was to detect the hard X-ray continuum and to investigate the presence of features indicative of AGN activity such as Fe-K lines. The original Genzel sample is composed of 15 ULIRGs: 4 of the remaining 5 objects are being observed anyway with XMM-Newton by different PI's (data will become public after 1-year proprietary period). For the last object (IRAS 23060+0505) adequate ASCA data are already public. Our aim will also be to combine our X-ray with other available data (XMM-Newton, *Chandra*, ASCA), as well as with information at other wavelengths.

3. XMM EPIC: DATA PREPARATION AND ANALYSIS

The XMM-Newton observations presented here have been performed between March 2001 and December 2001 with

the EPIC cameras operating in full-frame mode. Data have been processed using the Science Analysis Software (SAS version 5.2); the latest known calibration files and response matrices released by the EPIC team have been used.

Event files released from the SAS standard pipeline have been filtered from high-background time intervals and only events corresponding to pattern 0-12 for MOS and pattern 0 for PN have been used in the scientific analysis. The screening process from high background time intervals yielded net exposures between 16.3 ksec and 21.8 ksec (net exposures for PN camera are reported in Table 1).

All the 5 ULIRGs have been detected in the MOS1, MOS2 and PN detectors with signal to noise ratios greater than 3. Except for Mkn 231, which appears to be slightly extended, source spectra were extracted from circular regions of ~ 15 arcsec radius. Background spectra have been extracted from source-free circular regions of ~ 1 arcmin radius close to the target. Mkn 231 appears clearly extended (~ 40 arcsec) in the XMM-Newton images in particular in the soft X-ray band ($E < 2$ keV). In order to be less affected by the galaxy host emission we have chosen to extract the spectra from what appears to be the hard X-ray core of Mkn 231 (radius 15 arcsec). In order to improve the statistic, MOS1 and MOS2 data have been combined. Both MOS and PN spectra were then rebinned to have a $S/N \geq 2$ in each energy channel. The combined MOS data have been fitted simultaneously with PN data, keeping free the relative normalizations.

Table 1. Summary of the XMM-Newton accepted targets

Name	z	Log L_{IR}	EXP
		($10^{11} L_{\odot}$)	ksec
IRAS 12112+0305 ^a	0.072	17	/
MKN231 ^b	0.042	30	16.30
IRAS 14348-1447 ^a	0.082	18	/
IRAS 15250+3609 ^c	0.055	8.8	/
IRAS 17208-0014 ^c	0.043	21	/
IRAS 19254-7245	0.062	10	18.39
IRAS 20100-4156	0.129	33	18.09
IRAS 20551-4250	0.043	9.5	16.31
IRAS 22491-1808	0.078	12	21.77
IRAS 23128-5919 ^c	0.044	9.1	/

Note. a: source observed, data to be processed; b: very preliminary results; c: source to be observed.

4. PRELIMINARY RESULTS

4.1. IRAS 22491-1808 AND IRAS 20100-4156

IRAS 22491-1808 and IRAS 20100-4156 have been detected with a low significance which prevents us to perform a detailed spectral analysis. For these two sources we tried only two simple models: a thermal model and an absorbed power-law one. For both sources a single thermal or a single power-law model are both rejected from the data. The X-ray spectra of these two objects can be described with thermal model ($kT=0.86^{+0.19}_{-0.08}$ keV for IRAS 22491-1808 and $kT=0.67^{+0.37}_{-0.30}$ keV for IRAS 20100-4156), but evidence of an excess in the observed spectra at $E > 2$ keV is present. In order to account for this hard emission an absorbed power-law component has been added to the thermal model. Fixing $\Gamma = 1.7$ we obtain $N_H \sim 10^{20} \text{cm}^{-2}$ for IRAS 22491-1808 and $N_H \sim 10^{22} \text{cm}^{-2}$ for IRAS 20100-4156. The soft X-ray (0.5 – 2 keV) luminosities, corrected for absorption, are $\sim 2 \times 10^{41} \text{erg s}^{-1}$ (IRAS 22491-1808) and $\sim 5 \times 10^{41} \text{erg s}^{-1}$ (IRAS 20100-4156). The intrinsic hard (2 – 10 keV) X-ray luminosity is $\sim 10^{41} \text{erg s}^{-1}$ for IRAS 22491-1808 and $\sim 5 \times 10^{41} \text{erg s}^{-1}$ for IRAS 20100-4156.

4.2. IRAS 20551-4250

This source was previously observed with ASCA (Mitsuda et al. 1999) but the S/N ratio was very low. Thanks to the XMM-Newton throughput this source is now detected with an adequate S/N to perform a detailed spectral analysis. A good fit (see Figure 1) is obtained with a two components model: a thermal model ($kT=0.68^{+0.12}_{-0.07}$ keV) plus the so called “leaky-absorber” continua (this latter component is composed by an absorbed plus a non-absorbed power law model having the same photon index). We found that a good fit can be obtained with $\Gamma = 1.78^{+0.23}_{-0.24}$, a partial covering factor equal to $\sim 93\%$ and $N_H = 8.6 \times 10^{23} \text{cm}^{-2}$. The Iron line at 6.4 keV is not detected but the upper limit on its equivalent width (~ 1 keV) is consistent with the N_H value obtained from the fit. The intrinsic hard X-ray luminosity, corrected for absorption, of this object is $\sim 2 \times 10^{42} \text{erg s}^{-1}$ the soft X-ray luminosity is $\sim 10^{42} \text{erg s}^{-1}$.

4.3. IRAS19254-7245

From the analysis of the ASCA data (Imanishi M. and Ueno S. 1999; Pappa et al. 2000) two acceptable fits were proposed for this object: a) a non-absorbed power law model having a flat photon index ($\Gamma \sim 1$), and b) an absorbed power-law model with Γ fixed to 1.7 or 1.9 and $N_H \sim 10^{22} \text{cm}^{-2}$. No Iron line was clearly detected.

A single unabsorbed power law model is not a good description of the XMM-Newton data because of large discrepancies in the low energy domain. We have then added a thermal component obtaining a temperature $kT=0.98$ keV for the soft component and $\Gamma = 1.20^{+0.25}_{-0.30}$ ($N_H =$

Table 2. Observed ULIRGs Classification

Name (1)	Optical (2)	Mid-IR (3)	X-ray (4)
IRAS 20100-4156	HII	SB	AGN??
IRAS 20551-4250	HII	SB	AGN
IRAS 22491-1808	HII	SB	AGN?
IRAS 19254-7245	Sey2	AGN	AGN
Mkn 231	Sey1	AGN	AGN

Note. — Col.(1) Object name. Col.(2) Optical Classification (Lutz et al. 1999; Veilleux et al. 1999). Col.(3) Mid Infrared classification based on ISO spectroscopy (Genzel et al. 1998). Col.(4) X-ray Classification.

$3 \times 10^{21} \text{cm}^{-2}$) for the hard component (see Figure 2). The soft X-ray luminosity is $\sim 2 \times 10^{42} \text{erg s}^{-1}$. We also have evidence for an Iron line at 6.4 keV, whose high equivalent width (1.6 keV), together with the flat photon index, indicates that this object could be “Compton thick”, with the detected hard X-ray emission due to a pure reflected component. The intrinsic luminosity of the latter could be higher than the derived value of $\sim 10^{42} \text{erg s}^{-1}$.

4.4. MKN 231

Among the local ULIRGs, Mkn231 is the most luminous object (Soifer et al. 1984) and is one of the best studied at all wavelengths. Although it has been observed with many X-ray observatories (ROSAT, ASCA and more recently with *Chandra*), its X-ray properties remain still puzzling.

The AGN and starburst activities were clearly evident from ROSAT and ASCA data (Iwasawa et al. 1999; Turner 1999). However the flatness of the X-ray spectra at energies above 2 keV and the lack of any strong Fe line (Maloney & Reynolds 2000) was unusual;

these results have been confirmed by recent *Chandra* observations ($\Gamma = 1.3$, $\text{EW} < 188 \text{eV}$; Gallagher et al. 2001).

We have done only a preliminary analysis of the XMM-Newton data on Mkn 231 (the field containing the source is shown in Figure 3). Our results confirm the presence of a very flat spectrum ($\Gamma = 0.9$) and only a marginally detected, moderately intense, Iron line ($\text{EW} \sim 200 \text{eV}$). The intrinsic luminosity of the hard component is $\sim 3 \times 10^{42} \text{erg s}^{-1}$. A more complete analysis of Mkn 231 will be presented in a forthcoming paper.

5. CONCLUSION

All the 5 ULIRGs observed so far have been detected in X-rays by XMM-Newton. Although two of these sources (IRAS 20100-4156 and IRAS 22491-1808) are extremely faint, the presence of AGN activity cannot be ruled out by the data. For the remaining three sources, a clear evidence of AGN activity is found. In particular, for IRAS 19254-7254 we were able to detect the Iron $K\alpha$ line with an

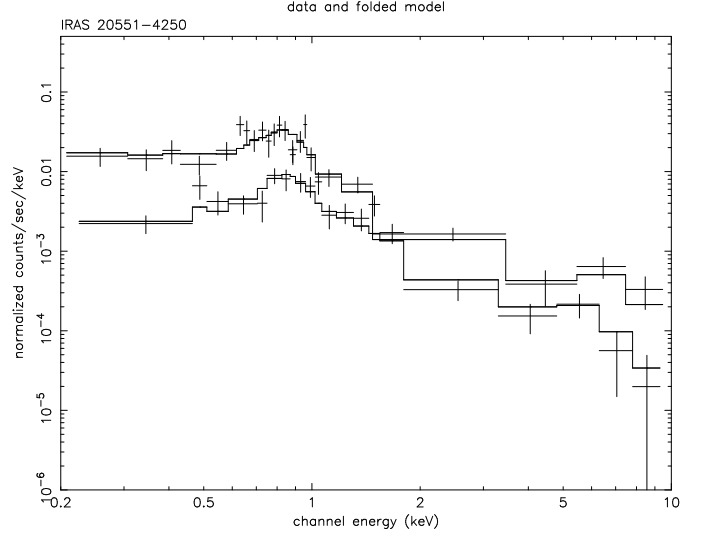


Figure 1. IRAS 20551-4250: MOS, PN data and folded model.

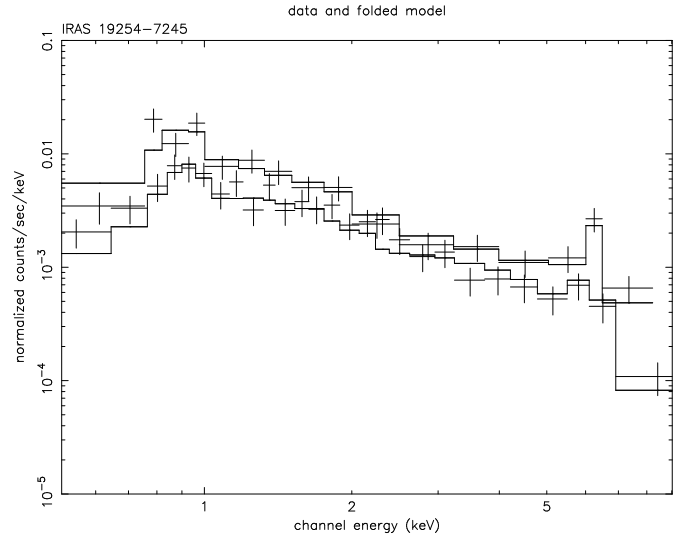


Figure 2. IRAS 19254-7245: MOS, PN data and folded model.

equivalent width $\sim 2 \text{keV}$, suggestive of a Compton-thick AGN.

What is emerging from our preliminary analysis is that AGN activity seems to be present in the majority of the ULIRGs observed so far. However, even if all the objects observed so far are “Compton thick”, their hard X-ray luminosities appear to be lower than $\sim 10^{44} \text{erg s}^{-1}$ even after correction for photoelectric absorption; this would indicate that these objects are not typically type-2 QSO, but more moderate buried AGNs. In any case, the intermediate nature of these sources is confirmed by our XMM-Newton survey.

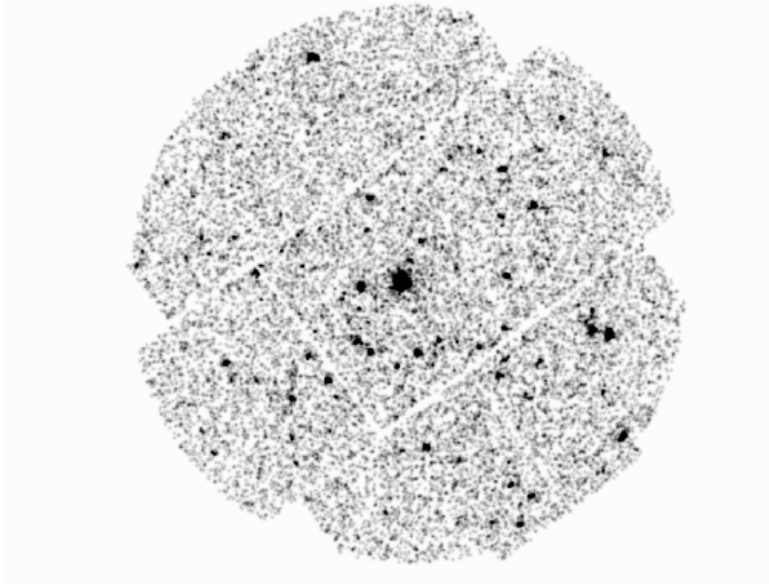


Figure 3. MOS2 (0.2 – 10 keV) image of Mkn 231 field.

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